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TORNADOES AND THEIR CAUSES.

THE fatality and frequency of tornadoes in the great Central West have recently invested these phenomena with an interest which must continually deepen as the regions they ravage become more thickly populated. The tornado is a local disturbance, its sweep limited, its duration at a given point but a few moments, and it is speedily exhausted, like the raving maniac, by the paroxysmal expenditure of energy. But if it lacks the vast geographical scope, the stately, ponderous tread, and the self-sustaining life of the ocean-hurricane or the regular continental cyclone, its masked, eagle-like movement and concentrated intensity make the fleeting meteor, which strikes and scars the earth as if it were hurled by a "supernal power," a more dreaded visitant and often a greater engine of destruction. There seems to be a wide-spread impression that, with the deforesting and settlement of the West, tornado-visitations have increased, so that a prominent journal recently raised the question whether their frequency and destructiveness will not have "a permanent effect on the settlement and prosperity of the country." We are even told that in some places the alarm created by these storms is so great that "the people are not only digging holes in the ground and building various cyclone-proof retreats, but in many instances persons are preparing to emigrate and abandon the country entirely." Whatever may be thought of such reports, the gravity of the subject warrants the present inquiry into the nature and causes of our interior tornadoes, as well as into the extent to which they can be foreseen and guarded against.

In this inquiry the term "tornado," it is premised, will be used in its proper sense—referring exclusively to that type of storm which, whether cyclonic or anti-cyclonic, is marked by excessive rarefaction, so that liquid, and even solid, bodies may be drawn up into its vortex, and which falls with more than "hurricane force" upon objects in its path—not confounding it with the "cyclone," or the "thunder-storm," both of which may be very destructive, but, nevertheless, generally manifest less intensity of action than the tornado. In many meteorological works, tornadoes figure under the titles "whirlwinds" and "*trombes*," and are sometimes termed "thunder-storms;" while marine tornadoes are called "waterspouts" ("*trombes de mer*"), and those of the desert, "dust-storms." Though the atmospheric conditions which usually attend tornadoes are similar to those originating the famous storms ("Pamperos") which, chiefly in summer, sweep down from the Andes on the Pampas of Buenos Ayres, the two phenomena are distinguishable.

The geographical areas within which the true tornado is most frequently developed, will be found in or near the extra-tropical regions, where the great anti-trade currents encounter the polar winds. On March 26, 1875, a typical Indian tornado occurred in the valley of the Jumna River, about three hundred miles south of the Himalaya Mountains, presaged by "a fiery appearance or ruddy glare" and "a booming, whirling sound as loud as the firing of a cannon," uprooting trees and moving in a "north-eastward" direction with the south-west monsoon. The similar Indian tornado of May 5, 1865, struck near Pandooah, on the East Indian Railway, cutting a track two hundred feet wide, destroying the greater part of two villages and killing twenty persons. The "dust-storms" of Upper India and Sind, described by Baddeley, carrying before them several distinct and large whirling columns of sand; the "vagrant" whirlwinds of Nubia, described by the African explorer, Baker, as occurring in April, May, and June, careering over the boundless desert, "traveling or waltzing in various directions;" the Mediterranean "typhoons," as Admiral Smyth calls them, the Australian "bursters," and our own tornado-belt, covering at least the whole Mississippi Valley, all help us to define the geographical parallels within which these meteors are most destructively felt. Europe, shielded by the Alps and other mountain-ranges, which serve to break the force of the anti-trade current, is comparatively exempt from tornadoes of the American type, though the Italian thunder-storms and the hail-storms of Southern France display, at times, force rivaling that of the tornado. Beyond the sixty-fifth parallel, Scoresby, in all his Arctic voyages, but twice witnessed lightning, and explorers of high latitudes (as Phipps, in 1773, and Parry, in 1827) have passed whole summers without seeing it. We may safely conclude that beyond fifty degrees north, while thunder-storms are not unknown, tornadoes are scarcely possible, and it is very doubtful whether a true tornado has ever been reported within ten degrees of the equator.

In thus defining the geographical limits of this storm, we may hope the better to get at its real nature and causes. A tornado consists of a mass of air in violent gyration, within which there is a center of rarefied air rising upward and flowing out above, the velocity of the surrounding atmosphere, drawn into the vortex below, increasing immensely as it nears the vacuum. Though in one sense a small cyclone, the tornado has a peculiar center, not disk-shaped, as that of the regular cyclone. One condition of its formation is no doubt the excessive heating of the lower atmospheric stratum, and its consequent expansion to such a degree that the vertical equilibrium is destroyed and convection currents suddenly set up. A simple experiment with a piece of smoking paper, placed under a burning drop-light fitted with a chimney, will show that the ascending smoke, in and after passing through the chimney, acquires a slight gyratory motion. The same motion takes place in any body of surface air, when the state of unstable equilibrium is established, and it shoots upward. A fine example of this was observed by Humboldt, when crossing the high South-American plateaux during the hot season. "The earth, wherever it appeared sterile and destitute of vegetation," he says, "was at the temperature of 86° to 90°; not a breath of wind was felt at the height at which we were on our mules; yet, in the midst of this apparent calm, whirls of dust incessantly arose, driven on by small currents of air which glide only over the surface of the ground, and are occasioned by the difference of temperature between the naked sand and the grass-covered spots." But, in the case of the tornado, some other force than that due to the destruction of stable equilibrium is necessary to account for the tremendous and long-sustained gyration. If a tornado could be formed by the simple action of the sun on the earth's crust, causing the superincumbent air to ascend, even though it should be in large masses, we should hear of tornadoes occurring over some parts of the country almost every day in summer. They would, moreover, instead of being confined mostly to the spring and first half of summer, be most frequent in the last half of summer, when the maximum temperature of the soil is reached, and we might confidently expect that many arid regions, where travelers have never encountered these storms, would be torn and furrowed with countless tornado tracks. It seems evident that the gyration of a real tornado (which is sometimes with and sometimes contrary to that of the clock hands) is not merely that which every ascending mass of air acquires, but a motion initiated or increased by the conflict of great aërial currents, one of which, at least, is moving with high velocity. "The whole column of gyrating air," as Professor Ferrel clearly puts it, "is like a tall flue containing very rarefied air, the centrifugal force of the gyrations acting as a barrier to prevent the inflow of air from all sides into the interior, and if the gyrations at the earth's surface were as rapid as those above, it would be similar to such a flue with all the draught cut off." Near the earth's surface, however, the gyrations and, consequently, the centrifugal force are greatly diminished by friction, and thus the air is allowed to rush in from below, and supply the draught of the ascending current. The tornado center may, therefore, be conceived of as a rapidly rotating, tall, and somewhat cylindrical body, moving erect or slightly inclined over the earth, and powerfully drawing up into its vortex all movable matter on the surface. The funnel-shaped cloud is formed around the upper part of the central whirl by the condensation of vapor carried upward to colder regions, and also, probably, by the condensation effected by the cold northwesterly winds which rush into the rear of the storm.

The progressive movement of such a meteor cannot be explained as is that of the ordinary cyclone. The average velocity with which continental and ocean cyclones travel, as deduced from hundreds of instances, is about twenty-five miles per hour. But the rate of translation observed in tornadoes is very much greater. The Alabama tornado of March 20, 1875, traveled seventy miles an hour over a portion of its track; the Georgia tornado of the same date sped on its disastrous way at the rate of fifty-seven miles an hour; the Illinois tornado of June 4, 1877, moved at the rate of thirty-seven miles an hour. The observed rate varies widely in different cases, but, perhaps, an average of forty-five miles an hour is attained by this class of storms. The ocean hurricane owes its progressive motion not only to the general atmospheric surface-current in which it is imbedded, but also to the fact that it is ceaselessly, while dying out in the rear, forming a fresh barometric depression in its front. If the tornado center is what it is supposed to be, it can hardly be conceived of as working its own way, with the tremendous velocity attributed to it, by the process of continual renewal in its front. Its translation must be due to the impulses it receives from the great atmospheric current in which it forms, and its velocity must be substantially that of any body borne along mechanically (as an eddy in a rushing stream of water) by the aërial current in which it is suspended. The West Indian hurricanes, while in the slow-moving trade-wind current, before they recurve on our South Atlantic coast, advance with a very tardy gait, and not infrequently remain nearly stationary for a day or two. The progressive motion of a tornado in the trade-wind belt would be much slower than that of a hurricane in the same location.

To get a clear idea of the tornado's behavior, we may briefly note the facts reliably reported by Mr. F. A. Howig, a citizen of Grinnell, Iowa, in connection with the tornado which overwhelmed that city on the 17th of June last. From the carefully written statement of this eye-witness, it appears the Grinnell tempest traversed the distance of about two hundred miles in four hours, pursuing a zigzag course. "It did not always visit the earth's surface, but often passed so far above as to inflict no injury, but again would swoop down with relentless fury, carrying destruction for a few miles to every object in its path." . . . "At about eight o'clock (P. M.) our attention was called to a most singular appearance of the sky a little south of west from Grinnell. It can be best described as like the reflection from the setting sun, yet in this instance such could not be the case, as it had not only disappeared below the horizon thirty minutes before, but the position of the phenomenon and the mass of dark clouds beyond would render such reflection impossible." Three or four hours previous "light, fleecy clouds" had overspread the sky, with but slight movement in any direction, and, subsequently (about 6.15 P. M.), "dark storm-clouds, were seen in the western horizon, moving slowly upward toward the zenith." But it was not till near 8.20, that the wind, "which at first was a gentle breeze, increased to a gale;" and twenty minutes later "the dreadful roar that preceded the coming of the destroyer was plainly heard in the north-west." "The storm-cloud proper," says this witness, "entered the city from the south-west, cutting a swath through the most densely populated portion seven hundred feet wide, killing forty persons instantly, displacing two heavy freight-trains from the rails, and carrying upward light objects to a great height, which were afterward found thirty and forty miles distant." In the Cincinnati tornado of May, 1809, there was a record of "violent cross-currents among the clouds," and a similar observation is generally made in tornadoes carefully reported. In that which Mr. Howig so graphically describes, the storm-bearing current was moving "from the south-west," but the fall of hail, and the roar "in the north-west," indicated the presence in the latter quarter of an opposing current.

The causes which operate in the initiation and translation of tornadoes are thus brought into view. The Mississippi Valley is a grand continental highway in summer for the vapor-laden trade-winds which, entering the Gulf of Mexico, are arrested in their westward movement, and must find an outlet to the northward. Moreover, the anti-trades, which form the "equatorial" current, are simultaneously pressing northward, especially at that season, as an upper atmospheric force, and after leaving the tropics stream away to the middle latitudes with a velocity which, if estimated by the observed velocity of the cirrus, cirro-stratus, and cirro-cumulus clouds, reaches, at times, one hundred and fifty miles an hour. As the Rev. Clement Ley, the English meteorologist, has observed, it is nothing uncommon to see these "upper-current clouds" moving from the south-west at the rate of one hundred miles an hour. Considering, then, the geographical relation of the Mississippi Valley to the great equatorial current which glides over it, gradually descending toward the surface of the earth, and which is underrun in summer by the trade-wind current diverted northward from the Gulf, it is not remarkable that our "Central West," lying also within reach of the polar winds from the Rocky Mountain plateaus, should be the scene of the most terrific aërial disturbances witnessed on any part of the globe. That the existence of an upper current from the tropics, flowing in a north-easterly direction in summer over the Mississippi Valley is not merely hypothetical, a glance at the wind observations made by the U. S. Signal Service at Pike's Peak, more than fourteen thousand feet above sea-level, will show. The result of these observations for 1874, "agrees," as Dr. Woeikof states, "with the generally entertained opinion as to the prevailing direction of the upper atmospheric current from the west-south-west, in the middle and northern latitudes." For the five years, 1875 to 1879, the prevailing winds at this high mountain station, as given in the Signal Service annual reports, were both in spring and summer, from the south-west, with a slight deviation in the summer of 1876; and during May and June (the chief tornado-months) of 1880 and 1881, the preponderance of winds on the Peak, as the Signal Service monthly means show, was in favor of the south-west. Were this lofty lookout station in Missouri, instead of in Colorado, the indications it affords of the sweep of the upper (or "return") trade current would in all probability be still more conclusive.

This vast atmospheric movement, the intensity of which augments as the summer solstice approaches, has apparently much to do with the origination of tornadoes. Being an outflow of ascended air from the equatorial calm belt, it advances northward with the vernal advance of the "thermal equator," which, by June, has followed the sun from "the line," nearly, if not quite, up to the lower Florida parallels. This movement may not be a steady "*Gulf Stream in the air*," as some have regarded it, but is rather to be viewed as a sustained series of pulsations from the medial line (the movable "thermal equator"), toward which the surface winds blow, and over which the air they bring must ascend and be massed, and, as it moves northward through high regions of the atmosphere, continually descends toward the earth's surface. To use the words of Mr. Colding, of Copenhagen: "As the upper currents of the atmosphere get beyond the tropics, the air grows heavier and gradually breaks its way (in our hemisphere) toward the north, alongside of the cold air-current which moves toward the equator." As the gap between the surfaces of the two currents depends on their velocity, "any chance stoppage of one of these currents," he reasons, "will cause it to impinge against the other, either from the north-west or south-east, thus producing an eddy which moves against the sun," and hence, the eddying winds thus formed, "under extraordinary circumstances, may increase to tornadoes or hurricanes, with all the corresponding natural phenomena." * The data hitherto collected, bearing on the remarkable characteristics of American tornadoes—their enormous progressive velocity, their "swooping down," or descending movements which make them so destructive, their display of electrical energy, the torrential rains that accompany them, and, above all, the coincidence between the sharply marked period of their occurrence with that in which the upper or return trade-wind current must be pressing northward with maximum force—all go to show that the explanation put forward by the Danish meteorologist and engineer of how these gigantic meteors may be formed, explains how many of them actually are formed. A striking confirmation of this conclusion is presented by the general direction of tornadoes, which is identical with that of the upper trade-wind and the anti-trades. The New Brunswick tornado of June 19, 1835, the great Natchez tornado of May 7, 1840, that at Cambridge, Mass., August 22, 1851, traveled from west-south-west toward east-north-east. Mr. Henry Calver, formerly of the Signal Bureau, who made a very careful study of these storms, reported: "In examining the history of over fifty tornadoes which have occurred in various portions of the United States during the last eighty years, I observe that the general course of these storms is eastward, with a greater or less defection toward the north." Therefore, he well suggests: "A person who saw a tornado approaching from the west might escape if he ran southward, while he would very probably be caught in the vortex if he ran northward." We cannot conceive of a tornado rushing along over the earth's surface, with a velocity of sixty or seventy miles an hour, in a north-easterly direction, without supposing it to be impelled by a *vis a tergo* acting on it mechanically from the south-west. If its direction were determined by surface-winds, caused by alternations of barometric pressure, and backing or shifting as neighboring areas of high and low pressure altered their relative positions, tornadoes would fly in every direction, and not be so uniformly confined to a north-eastward path. This is the tornado's normal path, as the most recent and comprehensive researches prove. The Book of Job, the scene of which was laid on the borders of the Syrian Desert—"the land of Uz"—was marvelously correct in saying: "Out of the south cometh the whirlwind."

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* See "Smithsonian Report," 1877, pp. 457-9.

The peculiarity of tornadoes in *descending* from the higher aërial strata and striking downward to the earth, while sweeping onward, is in keeping with the foregoing deductions. Leopold Von Buch was the first to show clearly the same tendency of the return trade-wind and the effect of its descent on the winds of the temperate zone. Humboldt, ascending the Peak of Teneriffe (twelve thousand eight hundred feet high), in the tropical Atlantic, on June 21st (the summer solstice), was scarcely able to keep on his feet for the violence of the return-trade, which Piazzi Smyth found, on the same cone, had no force at the altitude of nine thousand feet above the sea. The apparent *ricochetting* of tornadoes over the earth in the paths they traverse seems entirely accordant with their being borne bodily forward in the slowly descending upper trade-current, which becomes a surface-current beyond the torrid zone.

Again, the parallels of latitude on which tornadoes assail the earth seem to vary with the sun's vertical position north or south of the tropic, precisely as the whole belt of trade and anti-trade winds moves north and south, as the sun advances to the tropic or recedes from it. Thus, these storms usually descend on our Gulf-bordering States in the early spring, while their irruptions on the plains of the Upper Mississippi and Ohio Valleys occur in early summer; still later in the season, though rarely, they fall upon the Atlantic seaboard, north of Maryland—the Alleghanies, in the more elevated parts of the range, acting as a barrier which they cannot pass—but, with the sun's retreat southward, and the "remission of the south-westerly winds," which, Mr. Redfield points out, occurs in autumn, we hear no more of "Western Cyclones."* There are notable exceptions, but this appears to be the rule of their geographical range.

In this inquiry no attempt has been made to explain the intense rarefaction of air in the tornado-center, except by the centrifugal force of the air-masses, set in violent vorticose motion by opposing currents. "The forces of nature are few and simple," says Mr. William Blasius, whose investigations of tornado and cyclone phenomena have been long and well known, and for the production of a tornado, in his view, "only two opposing currents of air, in a peculiar but not uncommon condition, with a particular configuration of the earth, not at all infrequent," are necessary. The central vortex, it should be said, must—at least in a long-sustained tornado—be maintained by excessive condensation and precipitation of ascending aqueous vapor. The fact that tornadoes usually, if not always, burst upon the earth in the warm hours of the day (between one and nine P.M.), when the lower atmospheric strata are most heated, shows that the surface temperature conditions are also essential to their development. We do not propose to discuss the nicer dynamical questions suggested by the phenomena, but we cannot close without briefly viewing them from a practical stand-point.

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*A classification of twenty-five typical tornadoes (the most destructive meteors of this kind which have become historic), with reference to the parallels of latitude at which they descended to the earth, and to the months in which they occurred, shows, approximately:

Between March 1st and April 15th, five occurred in the mean latitude of 32° N. Between April 15th and May 30th, eight occurred in mean latitude 37° 45′ N. In June, six occurred in mean latitude 40° 45′ N. From July 1st to August 31st, six occurred in mean latitude 42° N.

Can tornadoes be foreseen and predicted? With a prompt telegraphic service, furnishing simultaneous weather reports from the threatened districts in the morning of each day, a competent meteorologist can certainly warn the public that the conditions favorable to the formation of these tempests exist, and, if present, he would often be able to give more specific warning. The barometer does not necessarily fall with the approach of the most fatal tornado, and the mercury may even rise in the instrument a short time before the well-marked signs of the storm appear. But when an area of low pressure is passing near and north of a place, with an area of comparatively high pressure struggling to get into its rear, the conditions are present for the formation, or, more correctly speaking, for the descent of an already formed tornado. As the critical hour of its appalling approach draws near, the painfully still and sultry air, the strange commotion in the upper atmosphere, "violent whirling of the clouds," "scud clouds moving in different directions," "the upper clouds moving briskly northward, indicating the existence of a southerly upper current," a vast volume of "inky-black and low moving cloud," sometimes of "dun," "dark-blue," or "coal-smoke" color, illuminated by electric discharges, occasionally in the shape of a funnel, an inverted cone, or an hour-glass, are among the surest and most carefully observed premonitory signs of the tornado's deafening roar, though its ominous noise is sometimes audible half an hour before its arrival. With such sky-portents, it is obvious that a local weather-watcher, apprised by timely weather-bulletins of the existence of conditions favoring the generation of tornadoes, would be in position to forewarn a Western village or town of impending danger. But it is probable that, for local warnings of this kind, each community will always have to rely mainly on itself, or upon its own State weather-service. The successful prediction of a full-fledged tornado is a triumph yet to be won by meteorology. For it almost seems,

> "The strife of fiends is on the battling clouds,
> The glare of hell is in these sulphurous lightnings;
> This is no earthly storm."

It is not beneath the dignity of the ablest investigators to find some safeguards for those communities whose homes are liable any day in summer to be ravaged by this fell destroyer. Is there any escape or protection from the tornado? Undoubtedly there is. It is true, the terrible meteor may descend with fatal effect on any spot near the path of its progress, whatever may be the topography of the country—hill or dale, or the flat prairie—in its *ricochet* motion. But as, with extraordinary uniformity, tornadoes have always been known, in our hemisphere, to travel from west-south-west to east-north-east, it would follow that a house or a town built in a valley running from south-east to north-west, or on the north-eastern and eastern slopes of a hill or range of hills, would be considerably sheltered, and the probabilities of a desolating visitation be greatly lessened. Even a gentle "rise" of ground, a little west-south-west of a town, might suffice to alter the tornado's course, causing it to rebound from the earth and pass over the otherwise devoted city. In selecting sites for Western farm-houses, railroad stations, and villages, it would certainly be very desirable to have regard to these considerations, giving the preference, *ceteris paribus*, to locations having an eminence on their westerly and southerly sides. Retreat, on the clear indications of this tempest, to cellars or excavations, is often the means of saving life. "Hundreds," on the approach of the recent Grinnell tornado, says the writer who describes it, "sought refuge in cellars and caves, and were thus saved from death, one only being killed who had taken this precaution." On the open prairie, where no topographical feature of the ground affords immunity, it cannot be considered superfluous for every household, when possible, to provide itself with underground and storm-proof retreats, having some means of ventilation in case the *débris* of wrecked houses should cover it.

Lastly, is there a probability that, with the closer settlement of the West, tornadoes will become more frequent? These storms have been vaguely recorded in early annals of the Mississippi Valley; but it must be admitted by all who have investigated such records that tornadoes of the type we have here considered were rarely witnessed by early western pioneers, or, if witnessed, the phenomena did not appear to them worthy of special and accurate mention. Indeed, it would be difficult to find in the many narratives of western exploration an account of such a tornado as recently destroyed Grinnell, though it seems highly probable that, had such a tempest visited any of the original settlements near the Mississippi with fatal results, it would have found numerous chroniclers. Historical accounts of hurricanes visiting the Carolinas and the Gulf States, in the memoirs of Drayton, Ramsey, Barton, Gayarré, and other writers, extend back beyond 1700; but we find few, if any, notices of clearly defined tornadoes occurring in this country during its colonial history. Had the latter disastrous storms been frequent at the time Mr. Jefferson (himself a painstaking meteorologist) wrote his "Notes on Virginia," and other extended and accurate accounts of the meteorological peculiarities of the country, they would certainly have figured in such dissertations more than they do. The paucity of references to well-marked tornadoes in early notices of American climatological events may, however, be easily ascribed to other causes than the absence of the phenomena. In the old forests, from the Gulf States to Canada, particularly in Western Pennsylvania and New York, as Mr. Blodget has noted, "the tracks of those (tornadoes) which prostrated the older growth a century since may still be traced by the belt of trees of uniform size and peculiar aspect which grew up subsequently." "From the clue to frequency which such tracks give, these storms," he adds, "must be placed at very remote intervals for any one locality." But, after weighing the reasons assigned for the apprehended increase of tornadoes—denudation and deforesting of the soil, and consequent diminution of rain-fall, and aridity of the country—they have apparently but little force. The clearing of the soil from its original vegetation, by increasing its power to radiate solar heat, and hence to initiate a condition of unstable equilibrium in the air, undoubtedly will exert a very slight influence in the production of these storms. But this condition is only one of several meteorological conditions requisite for the formation and descent of a tornado. If aridity of soil was sufficient to bring about the phenomenon in question, it would abound in the trans-Mississippi Plains more than in the immediate Mississippi

Valley, and in many rainless regions of the globe in which the tornado proper rarely occurs. Man's agency on the earth may, perhaps, slightly modify local climatic conditions. But, for the specific reasons here presented, man is as powerless to work any change which will augment or diminish the number of tornadoes, or to disturb the ponderous atmospheric machinery which produces them, as the puny fly is to retard or accelerate the motion of a powerful steam-engine. No such change can be wrought, without involving a derangement of all the grand factors of terrestrial climate, and destroying its permanence and stability. Plausible have been the various theories and prophecies put forth by some, announcing coming physical changes of grave import. But these meteorological catastrophists forget that the rain-drop and the storm—the humblest and the grandest phenomena of the atmosphere—owe their existence to the same cyclopean forces, and that these forces are unabated by any changes known to be going on upon the earth's surface. We may safely turn for relief from such theories to that primitive promise which was given to Noah, and which abides uninvalidated: "While the earth remaineth, seed-time and harvest, and cold and heat, and summer and winter, and day and night, shall not cease."

T. B. Maury.